LABORATORY TESTING OF ELECTRO-OSMOTIC PULSE TECHNOLOGY TO REDUCE AND MAINTAIN LOW MOISTURE CONTENT IN CONCRETE

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Outline

- Background
- Electro-Osmotic Pulse (EOP) Technology Description
- EOP Field Test
- Laboratory Testing
  - Specimen Preparation
  - Specimen Testing
  - Test Results
- Conclusions

Background

- Work performed as part of US DoD Corrosion Prevention and Control Program
- Funding
  - 50% OSD ATL
  - 50% Army ACSIM-IMCOM

Background

- Problems due to moisture
  - Corrosion
    - Equipment
    - Structural Reinforcing
  - Mold & Mildew
  - Poor Air Quality

EOP Technology

- EOP Technology stops water intrusion through concrete
  - Creates electro-osmotic force to counter wet side hydraulic forces
    - Head
    - Equilibrium
- Side benefit of EOP include
  - Extends life of concrete injection materials
  - Reduces corrosion of interior assets
  - Improves indoor air quality

Fundamentals of Electro-osmosis

Fundamental forces influencing the movement of a solution in a capillary.

$$\rho \frac{d\vec{v}}{dt} = \bar{g}\rho - grad\rho + \eta\nabla^2\vec{v}^0 + \left(\frac{\rho^+ z^+ e_0}{m^+} + \frac{\rho^- z^- e_0}{m^-}\right)\vec{E} - \frac{kT}{m^+} grad\rho^+ - \frac{kT}{m^-} grad\rho^-$$

$\bar{g}\rho$	Gravity
$-\,\mathrm{grad}\; p$	Pressure*
$+\,\eta\nabla^2\vec{v}^0$	Viscosity
$+\left(\frac{\rho^+ z^+ e_0}{m^+} + \frac{\rho^- z^- e_0}{m^-}\right)\vec{E}$	Electro-osmosis*
$-\frac{kT}{m^+}\,\mathrm{grad}\,\rho^+ - \frac{kT}{m^-}\,\mathrm{grad}\,\rho^-$	Temperature

Fundamentals of Electro-osmosis

Definitions of variables in fundamental equation of electro-osmosis.

$\rho = \text{density of the solution}$

$\rho^{\pm} = \text{density of the medium of the positive (negative) ions}$

$\vec{v} = \text{velocity of the solution (center of mass)}$

$\vec{v}^{0} = \text{velocity of the solvent}$

$\bar{g} = \text{acceleration of gravity}$

$p = \text{pressure}$

$\eta = \text{shear viscosity coefficient}$

$z^{\pm} = \text{charge of an ion}$

$e_0 = \text{elementary electric charge}$

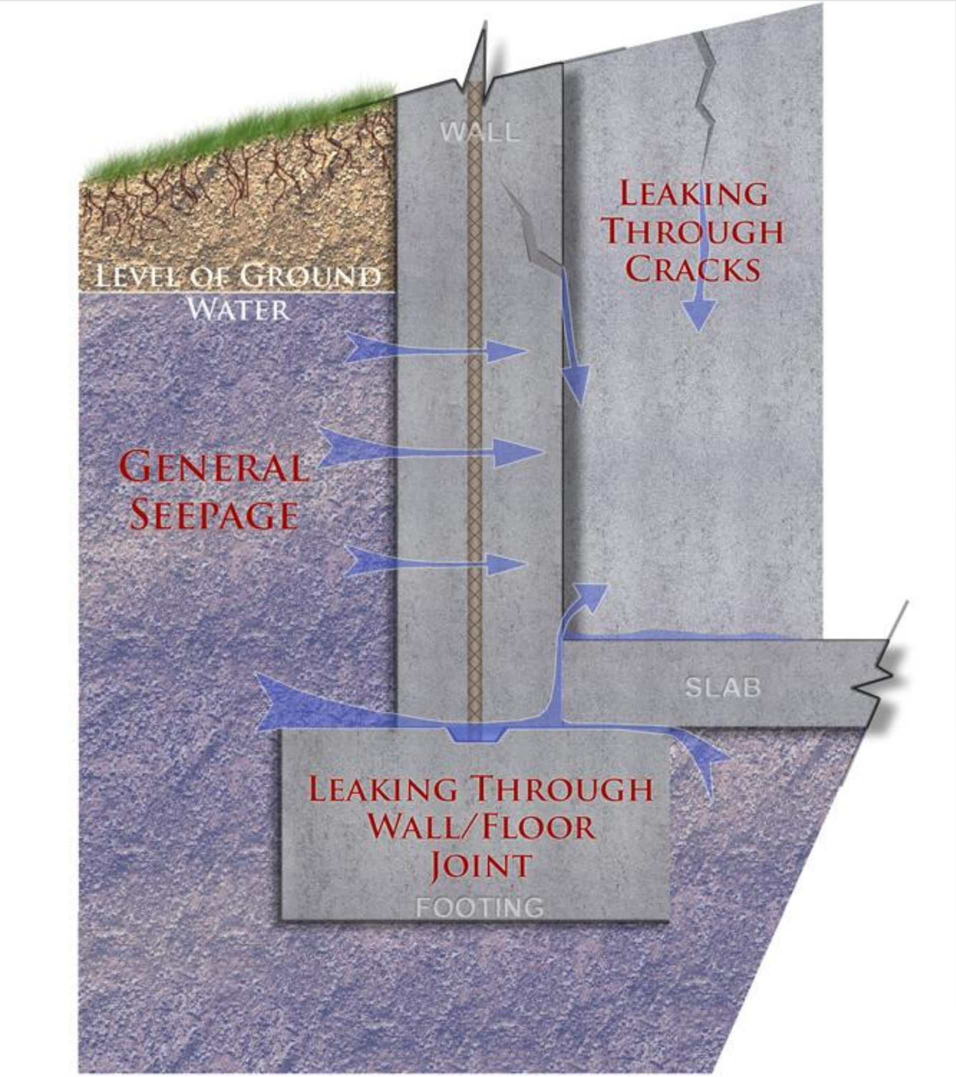
$m^{\pm} = \text{mass of a positive (negative) ion}$

$\vec{E} = \text{strength of the electric field of the system}$

$k = \text{Boltzman constant}$

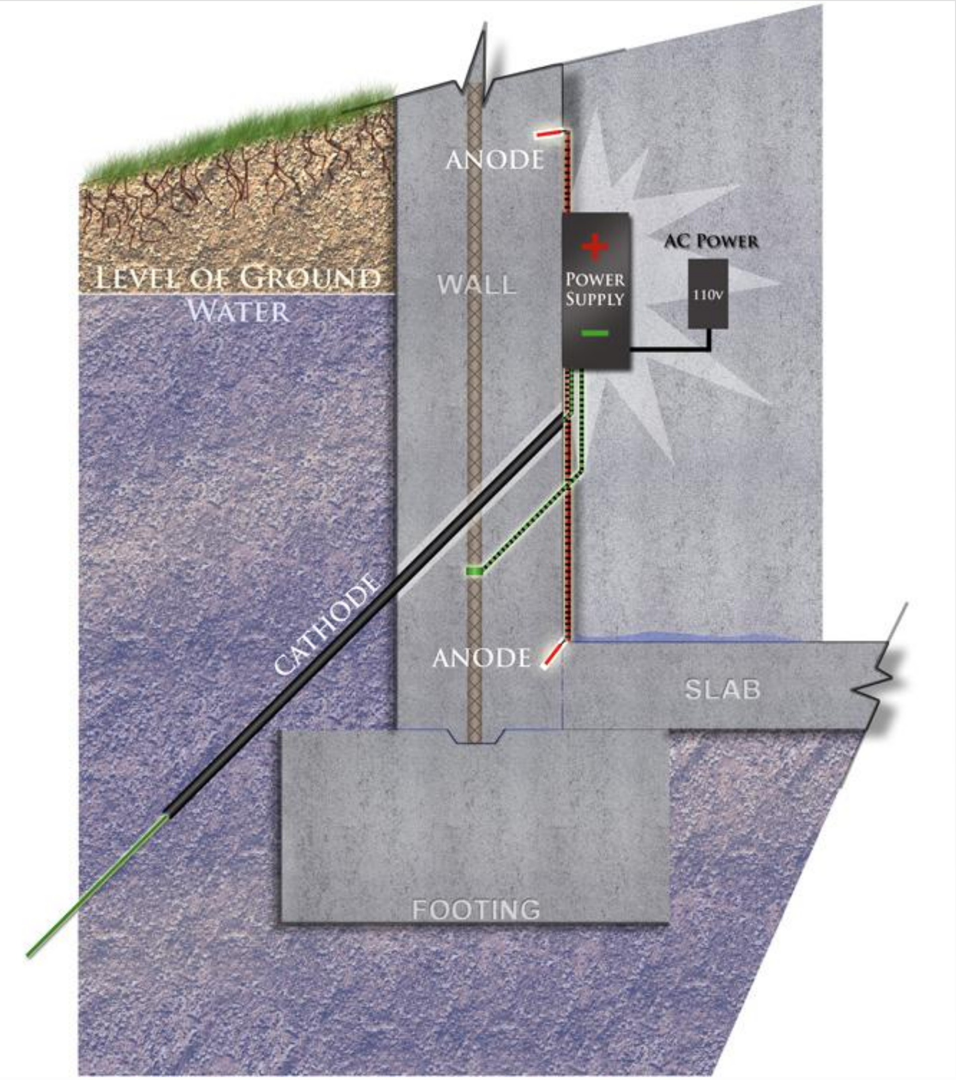
$T = \text{temperature}$

Principles of EOP Technology



Water can enter a structure via seepage or through joints and cracks.

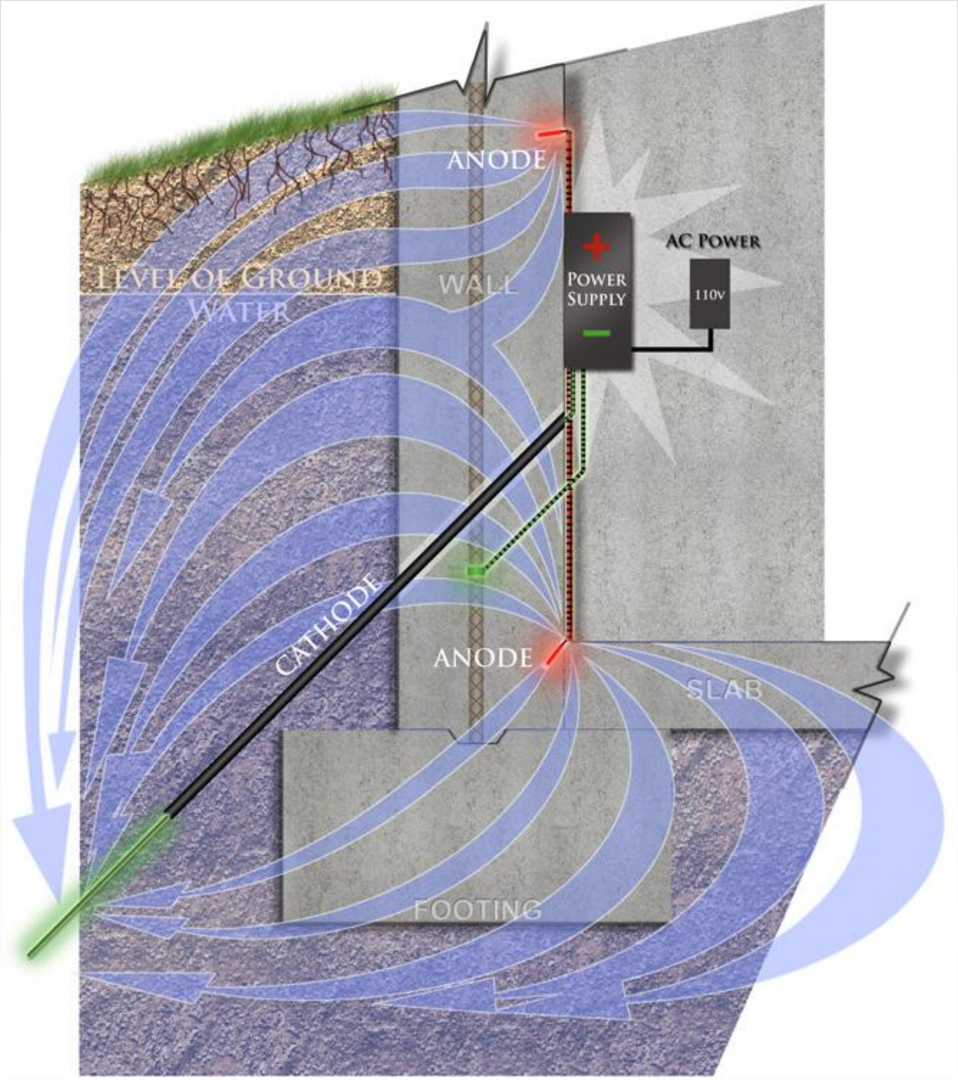
Principles of EOP Technology



Electrodes are installed in the concrete and the adjacent soil.

A small voltage (up to 30 VDC) is applied between the electrodes producing an electric field across the concrete.

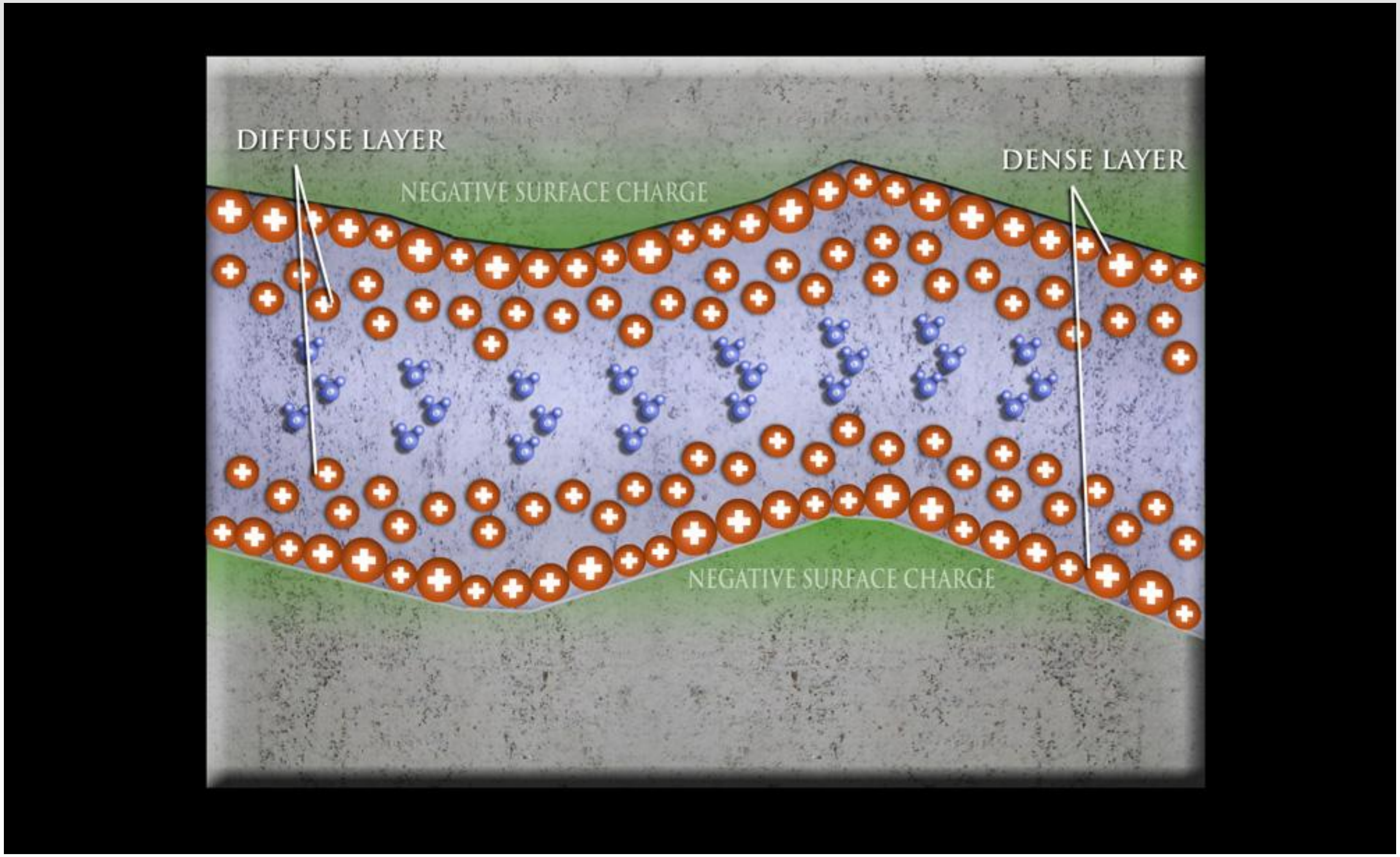
Principles of EOP Technology



The electric field promotes cation, anion, and water molecule movement within the concrete; creates counterflow and associated pressure that opposes seepage; pulse technology allows some moisture to be retained within the concrete preventing overdrying.

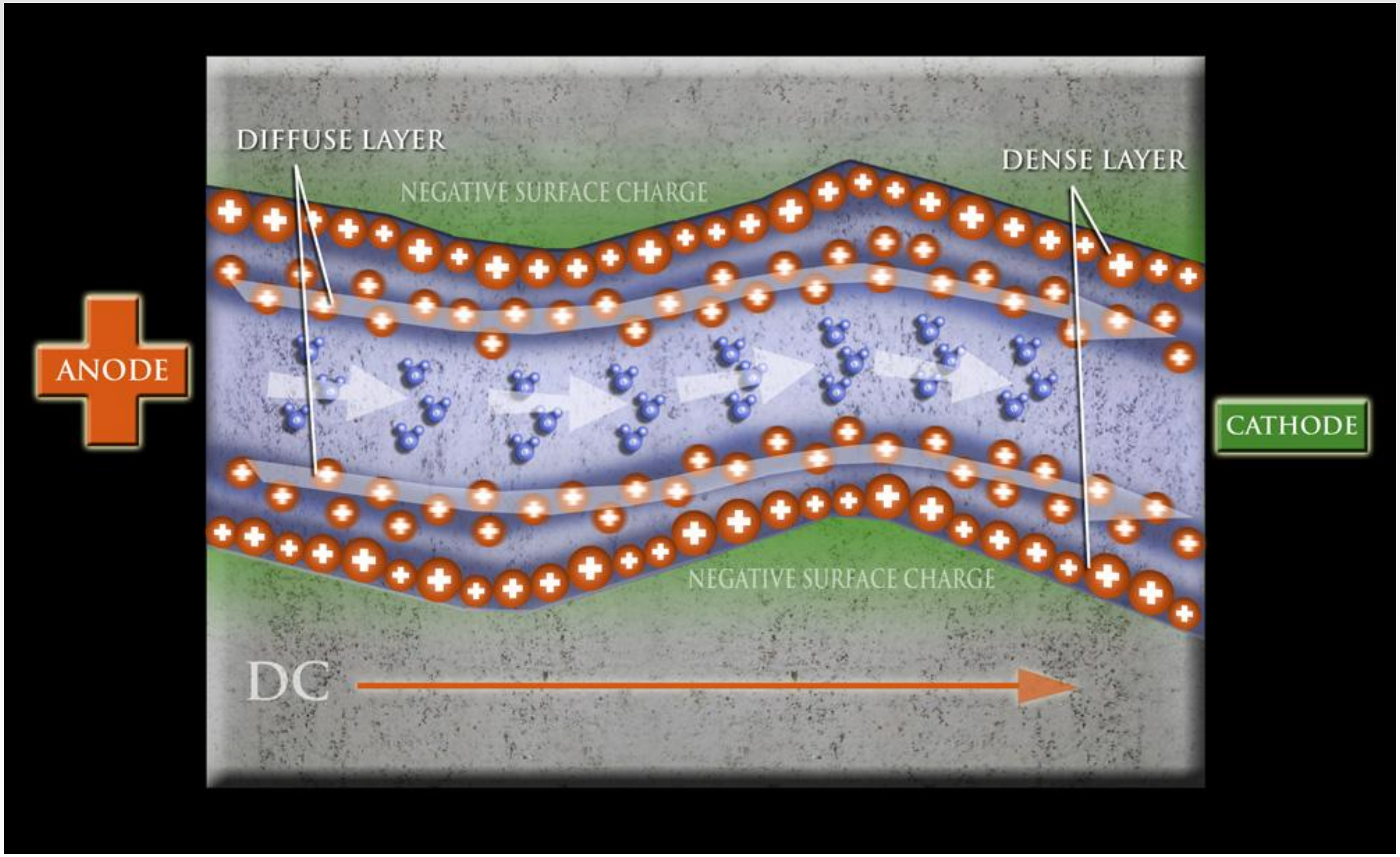
Fundamentals of Electro-osmosis

The basic requirement for electro-osmosis is a capillary with an electrical double layer.



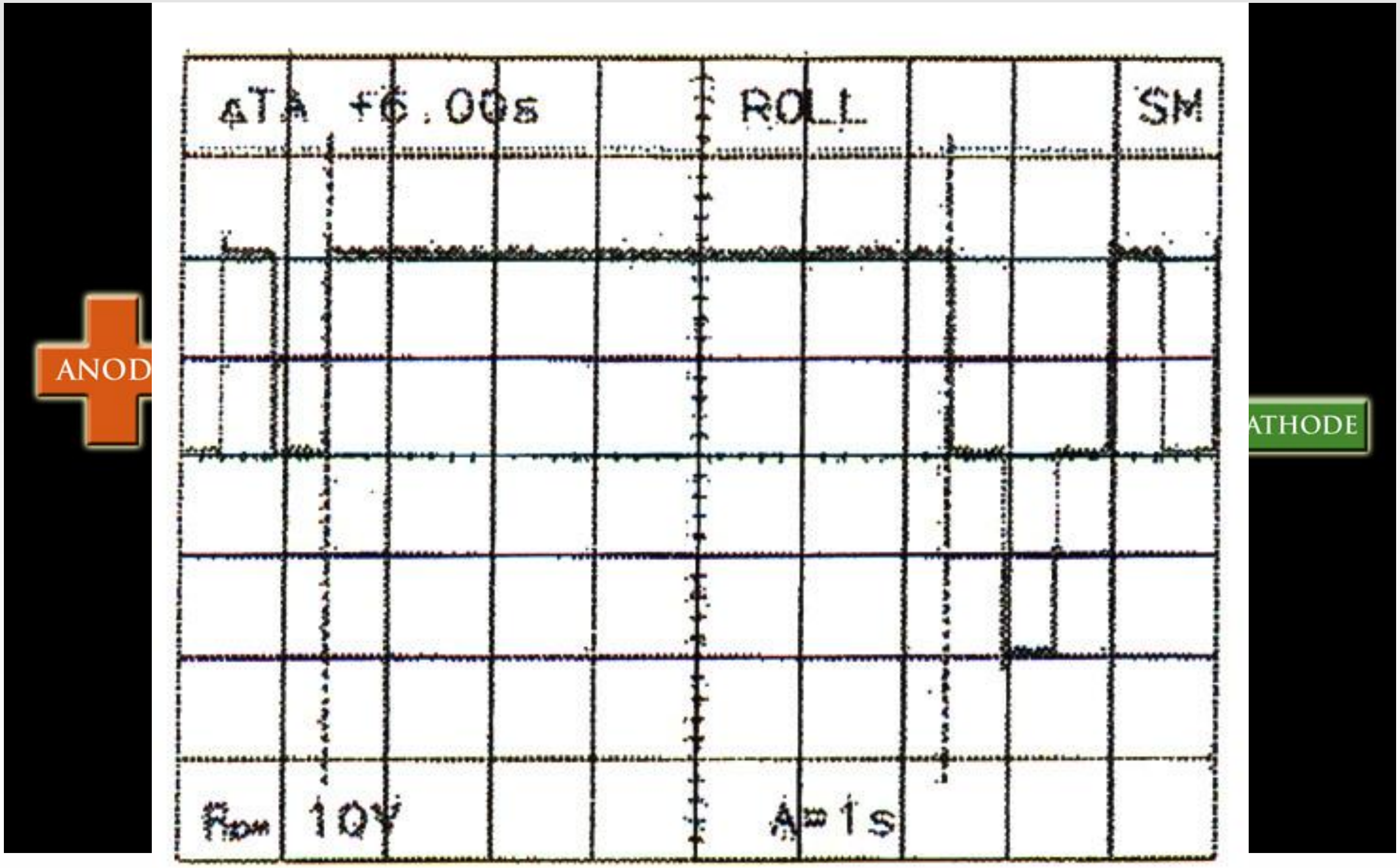
Fundamentals of Electro-osmosis

Application of an electric field across the capillary causes the positive ions and the solution to move from the anode to the cathode.



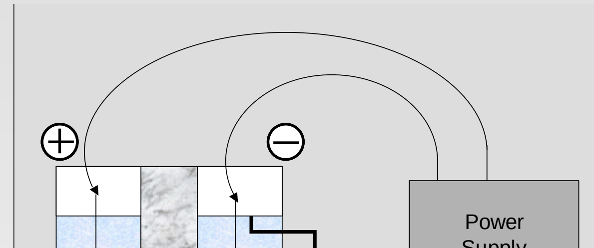
Principles of EOP Technology

Pulse technology minimizes harmful effects to concrete and rebar and prevents over drying, pore blocking and electrode polarization.



Electro-osmotic Laboratory Experiments with Concrete

- Measure solution transport rate through concrete and CMU
- Monitor:
  - Mass Transport
  - Electrical Current
  - Electrical Gradient along transport path



Electro-osmotic Laboratory Experiments with Concrete

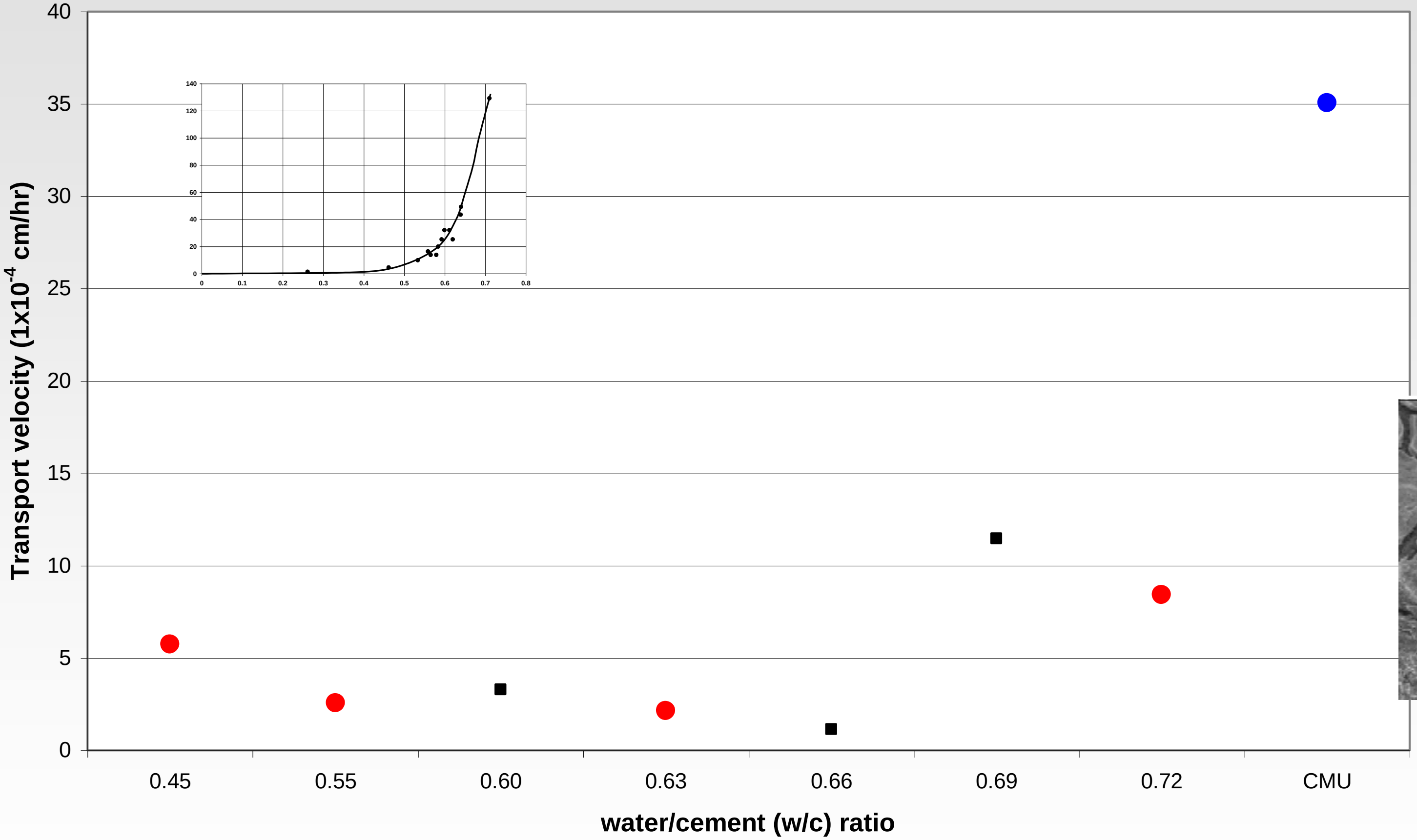
Specimen (w/c ratio – thickness)	V (cm/sec)	EO transport rate (cm^3/sec)	Hydraulic transport rate 305-cm (10-foot) head (cm^3/sec)
0.45 – 10	15.98×10^{-8}	5.75×10^{-5}	0.44×10^{-7}
0.55 – 10	7.11×10^{-8}	2.56×10^{-5}	1.65×10^{-7}
0.63 – 10	5.96×10^{-8}	2.15×10^{-5}	4.39×10^{-7}
0.72 – 10	23.39×10^{-8}	8.42×10^{-5}	15.37×10^{-7}
CMU – 5	97.41×10^{-8}	35.07×10^{-5}	Not computed
0.63 – 5	18.79×10^{-8}	6.76×10^{-5}	8.78×10^{-7}
0.69 – 5	14.20×10^{-8}	5.11×10^{-5}	25.25×10^{-7}

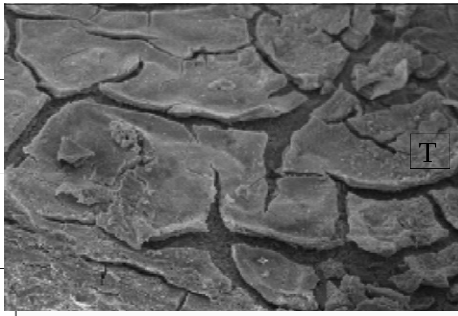
Electro-osmotic versus hydraulic transport rates of various specimens.

Electro-osmosis is 100 times more effective at moving water through concrete than a hydraulic head (pressure).

Electro-osmotic Laboratory Experiments with Concrete

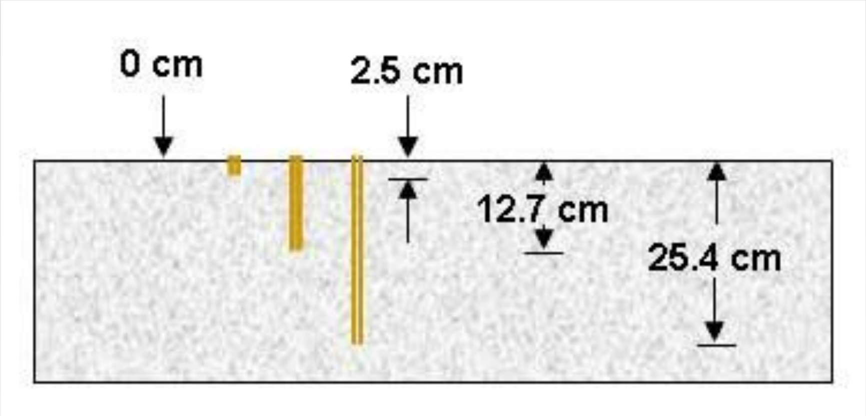
Transport velocity for 10-cm thick concrete specimens and CMU

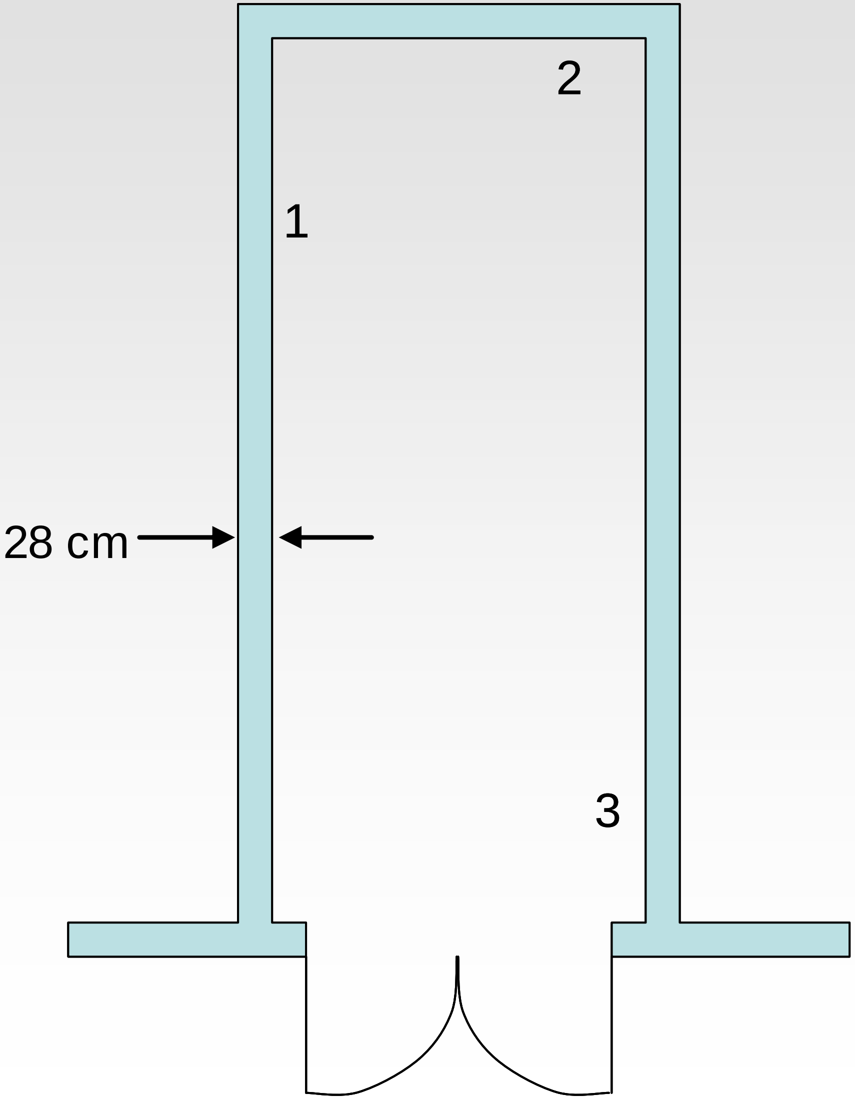




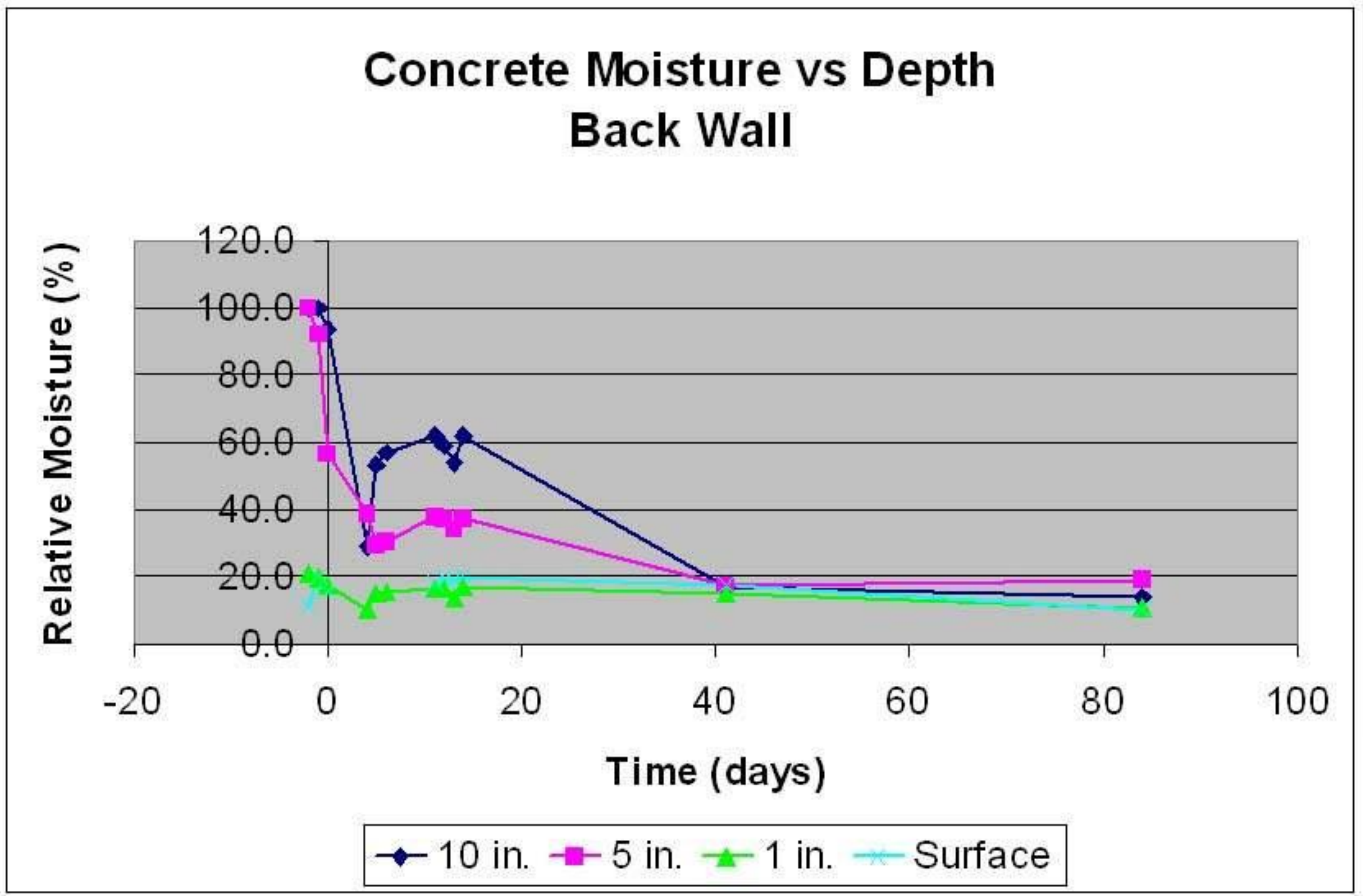
Field Test

Field Test



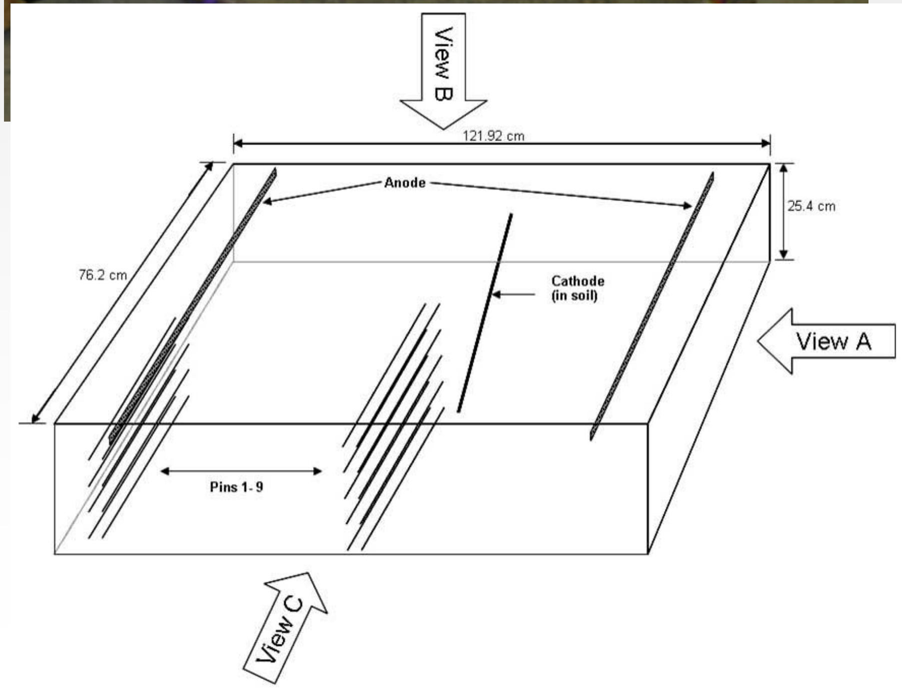


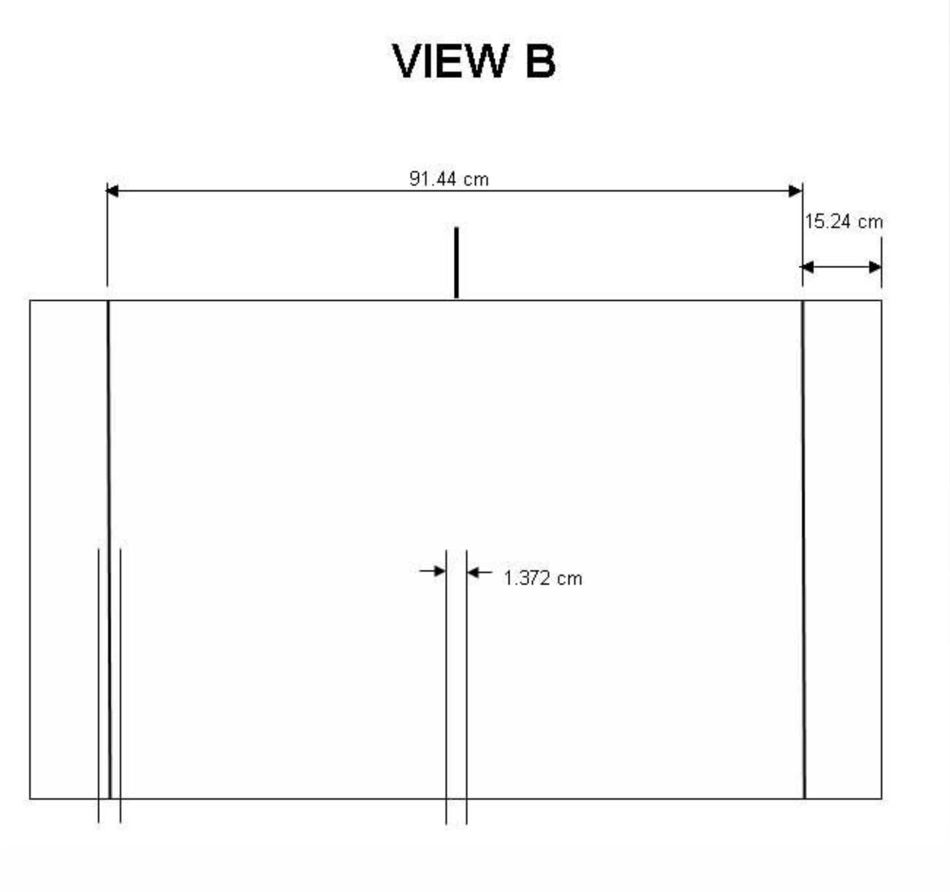
Field Test


Concrete Moisture vs Depth
Back Wall
Relative Moisture (%)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
-20
0
20
40
60
80
100
Time (days)
10 in.
5 in.
1 in.
Surface

Laboratory Testing

Laboratory Testing





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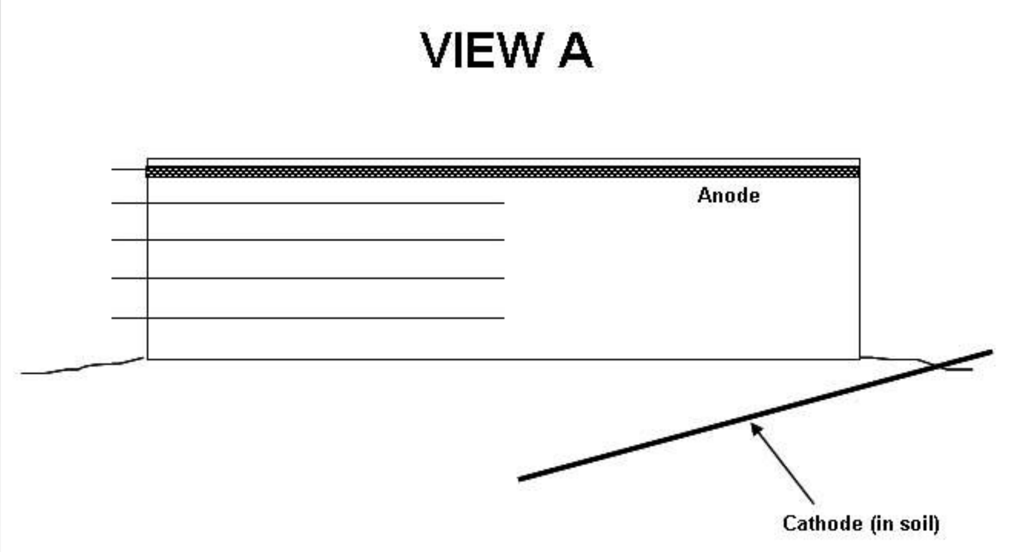

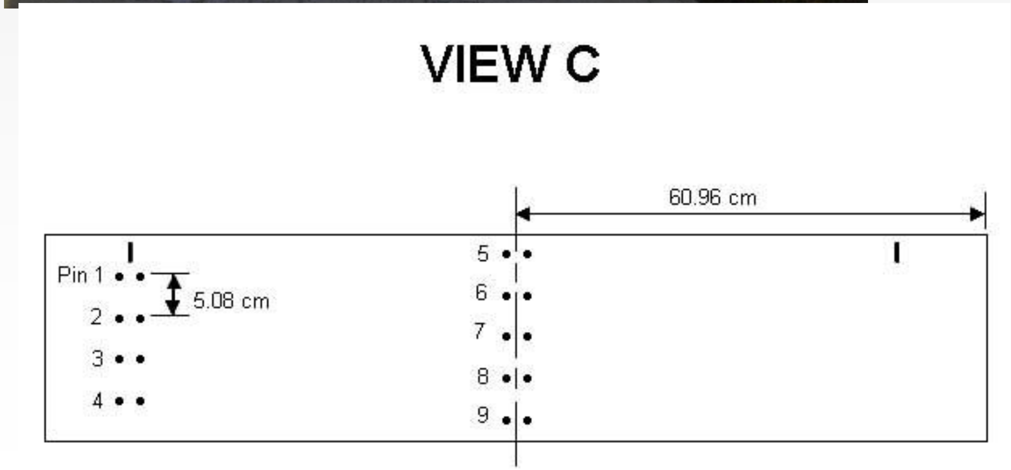

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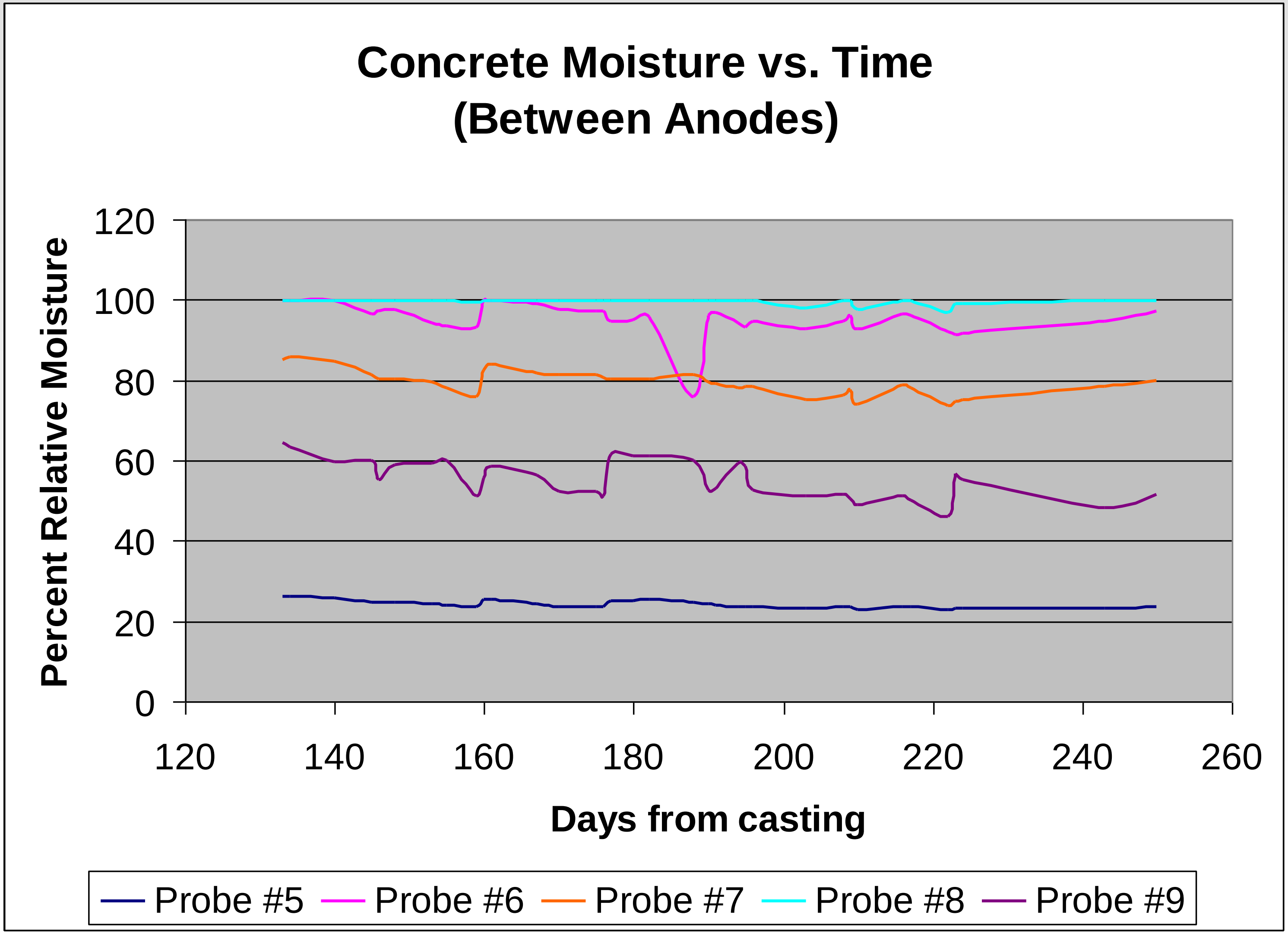

Laboratory Testing

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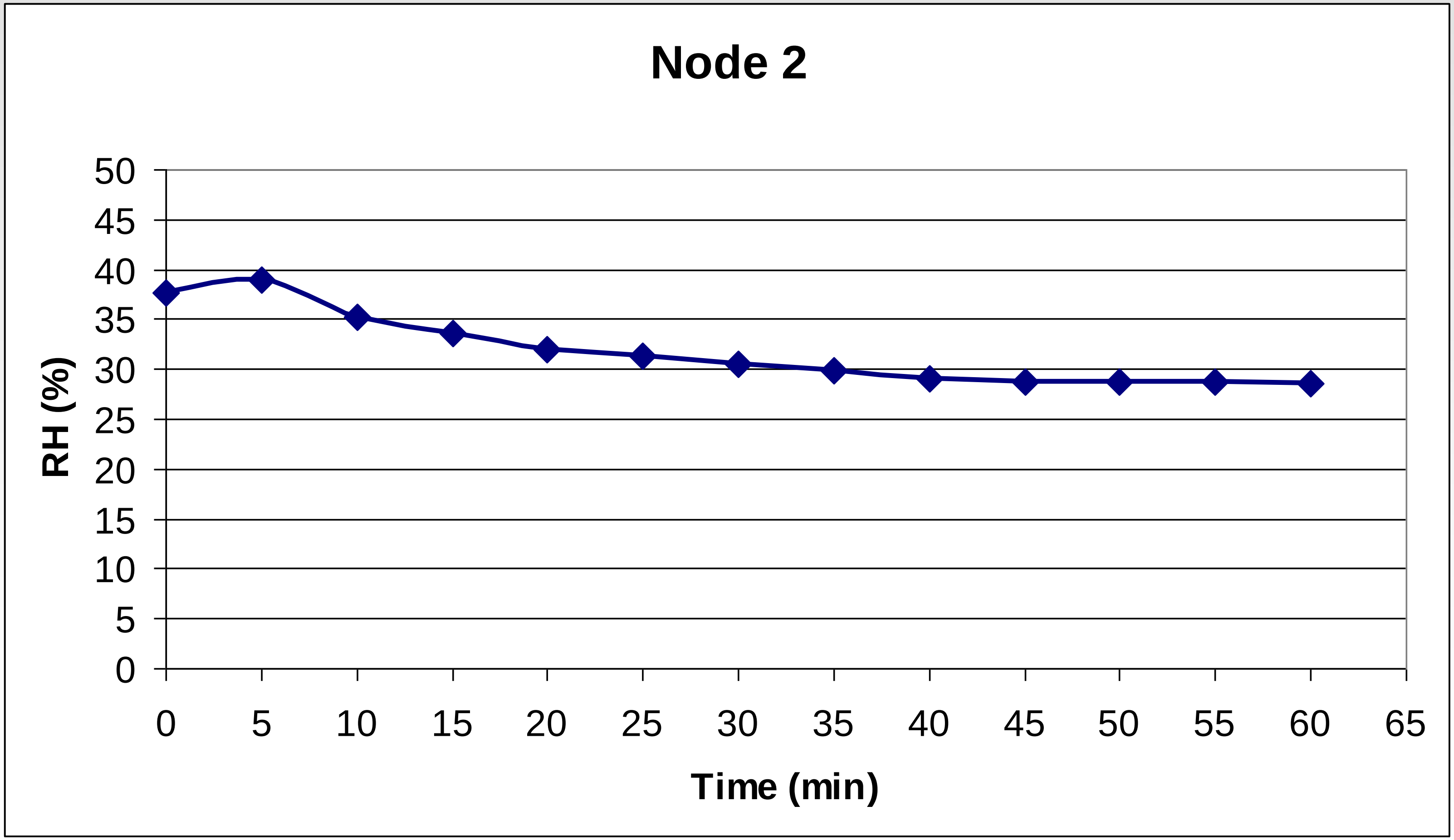
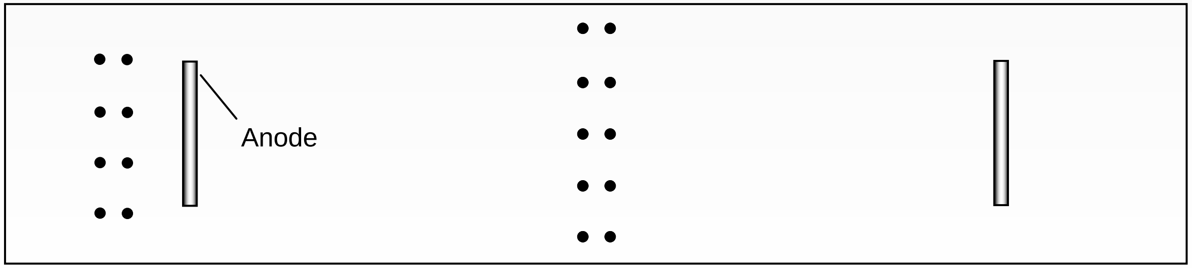


Laboratory Testing

Date	AverageFlow Rate (L/hr)
27-Mar-08	0.8
28-Mar-08	0.59
2-Apr-08	0.9
8-Apr-08	0.475
17-Apr-08	0.67
AVERAGE	**0.687**

Laboratory Testing



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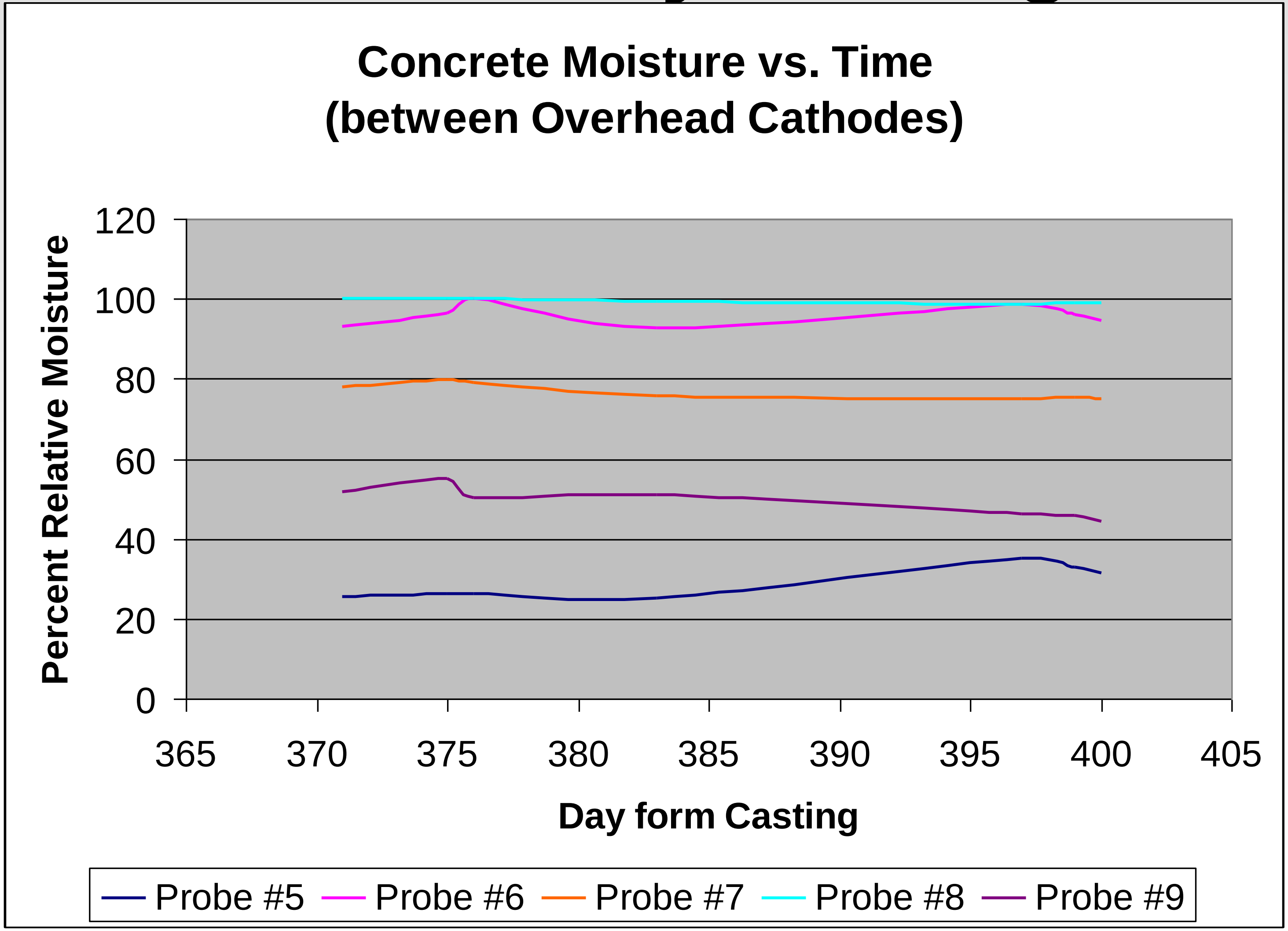

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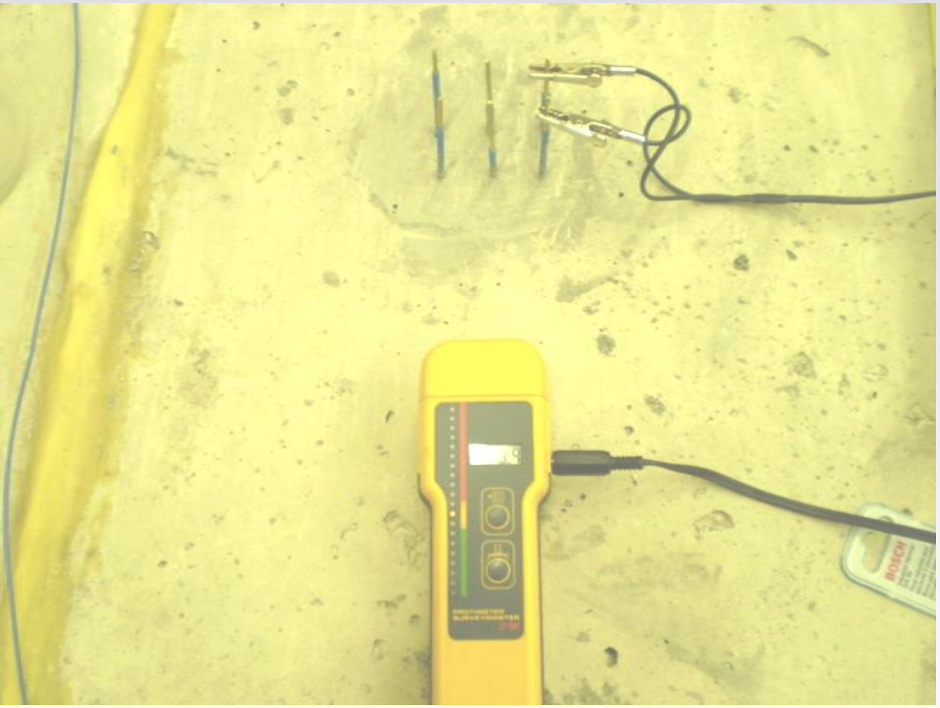

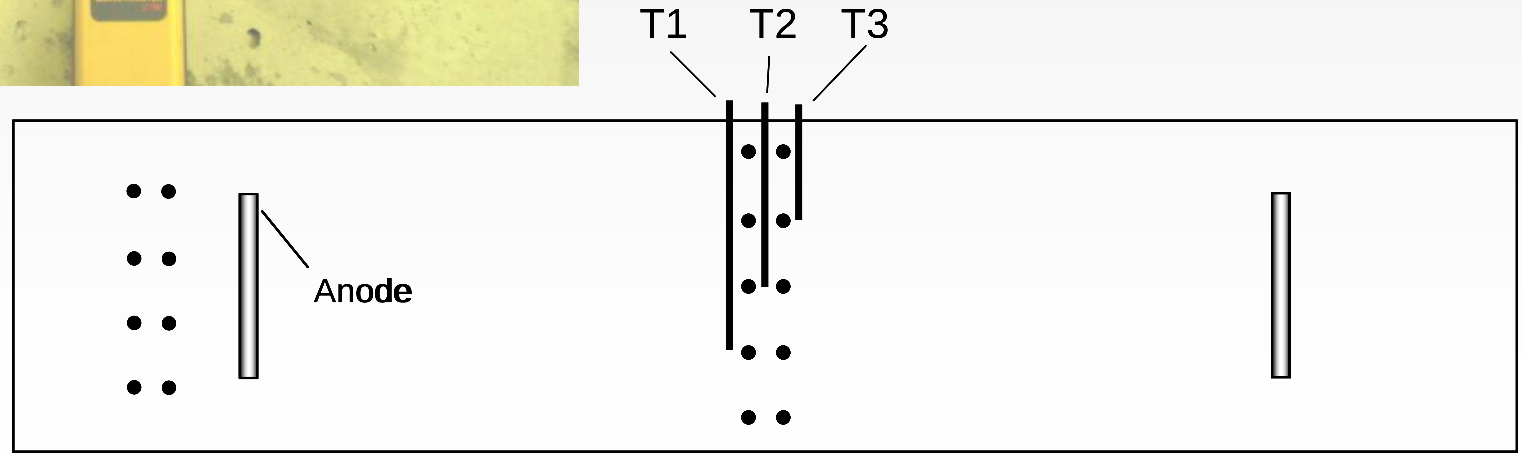

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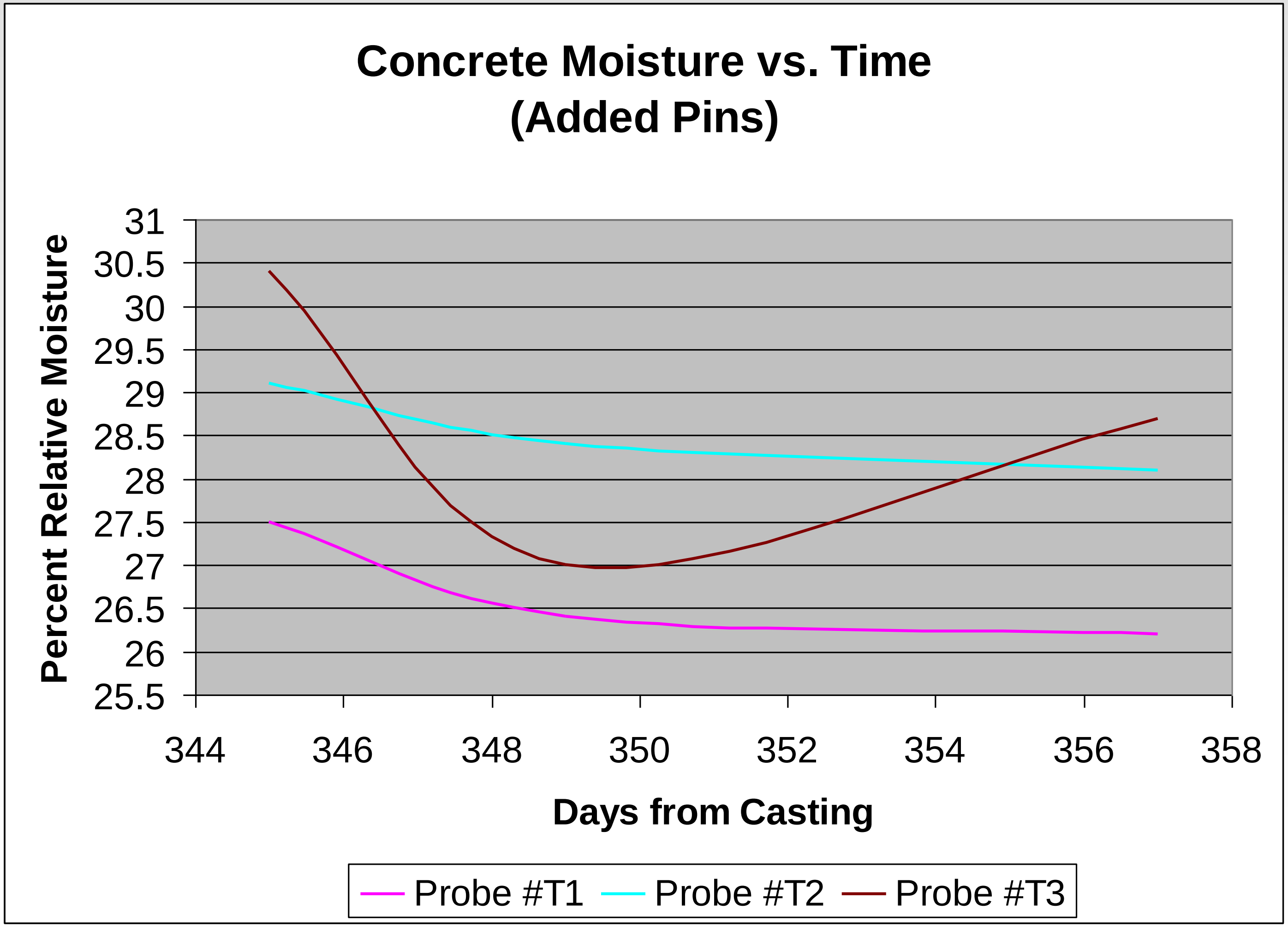

#8 #7 #6

CONCLUSIONS

- EOP is be effective in moving moisture in the surface through it without significant increase in internal moisture.
- When the anodes are placed interior to the concrete with the cathodes near the surface where water can penetrate, EOP will block water entry into the interior of the concrete.
- Test data for probe locations 6, 7 and 8 are suspect due to a high probability of a void or occlusion at the ends of the probes created when the test specimen was cast.

QUESTIONS